SOFT HANDOFF BETWEEN CELLULAR SYSTEMS EMPLOYING DIFFERENT ENCODING RATES

`Field of the Invention

The present invention relates generally to cellular communication systems and in particular, to soft handoff between such systems employing different encoding rates.

Background of the Invention

During transmission within a cellular communication system, data that is transmitted is error protected in several ways prior to transmission. One form of error protection is convolutional encoding. During encoding, a convolutional encoder encodes input data bits into data symbols at a fixed encoding rate (r) with an encoding algorithm which facilitates subsequent maximum likelihood decoding of the data symbols into data bits (e.g. convolutional or block coding algorithms). For example, a convolutional encoder encodes input data bits (received at a particular bit rate) at a fixed encoding rate of one data bit to n data symbols (rate $1/n$) such that the convolutional encoder outputs data symbols at a $n*r$ ksymbol/second rate.

Such a convolutional encoder is illustrated in FIG. 1. The memory of encoder 100 is characterized by its state, which is represented as a v-bit binary number $X = x_0 x_1 \ldots x_{v-1}$. For every input bit, the encoder outputs n bits based on the input and v state bits, and then transitions to a next state. More particularly, for every bit that enters the encoder, that bit is stored in the leftmost memory location, and all pre-stored bits are shifted to the right. Two calculations (g_0 and g_1) are made each bit time by exclusive OR'ing the contents of the specified shift register locations as shown.

Currently 2nd generation Code Division Multiple Access (CDMA) systems utilize a rate ½ convolutional encoding on the downlink, and a rate ¼ convolutional encoding on the uplink, while 3rd Generation systems can utilize $^1/_3$, ¼, or 1/6 rate convolutional encoding. A problem exists when a mobile unit with 2nd Generation and 3rd Generation capabilities (dual mode) is in inter-system soft

handoff between systems employing two differing encoding rates. In such a system the combining of multiple forward links cannot be accomplished. This is because different encoder rates of the multiple air interface systems produce a different number of encoded symbols (with the same encoder constraint length K, for example K=9), which cannot be combined. Therefore, a need exists for a method and apparatus for performing soft handoff between systems employing different encoding rates.

Brief Description of the Drawings

FIG. 1 is a block diagram of a prior art convolutional encoder.

FIG. 2 is a block diagram of a mobile receiver in accordance with the preferred embodiment of the present invention.

FIG. 3 is a block diagram of the decoder of FIG. 2 in accordance with the preferred embodiment of the present invention.

FIG. 4 is a flow chart showing operation of the decoder of FIG. 3 in accordance with the preferred embodiment of the present invention.

FIG. 5 is a block diagram of a decoder in accordance with an alternate embodiment of the present invention.

FIG. 6 is a flow chart showing operation of the decoder of FIG. 5 in accordance with the alternate embodiment of the present invention.

Detailed Description of the Drawings

To address the above-mentioned need soft handoff between cellular systems employing different encoding rates is provided herein. A receiver is provided receiving signals from differing base stations (BTS_A and BTS_B). The signal from BTS_A is encoded using a first rate convolutional encoder while the same signal transmitted from BTS_B is encoded using a second rate convolutional encoder. Since the multiple base station links may result in a different number of symbols being received for each bit transmitted, the symbols received for each link cannot be simply combined. Therefore, in the preferred embodiment of the present invention, the resulting symbols are passed to multiple branch metric

circuits, where branch metrics (μ_i) for the symbols are obtained. After the i^{th} branch metrics for the base stations are computed, the branch metrics for each base station are passed to a combiner where they are combined.

Because the branch metrics from each of the base stations are added together to form a combined branch metric, the diversity combining gains of soft handoff can be achieved for inter-system (generation) soft handoff. This allows for the diversity benefit of soft handoff to be achieved for systems employing different convolutional encoding schemes.

The present invention encompasses an apparatus comprising a first signal path and a second signal path. The first signal path comprises a first despreader, a second despreader coupled to the first despreader, a first de-interleaver coupled to the second despreader, a first branch metric determiner coupled to the first de-interleaver, wherein the first branch metric determiner outputs first branch metrics. The second signal path comprises a third despreader, a fourth despreader coupled to the third despreader, a second de-interleaver coupled to the fourth despreader, a second branch metric determiner coupled to the second de-interleaver, wherein the second branch metric determiner outputs second branch metrics. Finally, the apparatus includes a combiner having the first and the second branch metrics as an input and outputting combined branch metrics.

The present invention additionally encompasses an apparatus comprising a first branch metric generator having a first plurality of symbols as an input and outputting first branch metrics for the first plurality of symbols, a second branch metric generator having a second plurality of symbols as an input and outputting second branch metrics for the second plurality of symbols, and a combiner having the first and the second branch metrics as an input and outputting combined branch metrics.

The present invention additionally encompasses a method. The method comprises the steps of receiving a first plurality of symbols, and generating first branch metrics for the first plurality of symbols. A second plurality of symbols is received and second branch metrics are generated for the second plurality of symbols. Finally the first and the second branch metrics are combined.

The description of the preferred and alternate embodiments will be given below with respect to functionality existing within a mobile unit receiver. One or ordinary skill in the art will recognize, however, that the preferred and alternate

embodiments may be implemented within cellular infrastructure equipment receivers (e.g., a base station receivers) as well.

Turning now to the drawings, wherein like numerals designate like components, FIG. 2 is a block diagram of receiver 200 in accordance with the preferred embodiment of the present invention. As shown, receiver 200 is receiving two signals from differing base stations (BTS_A and BTS_B). For the purposes of the following discussion, the signal from BTS_A is encoded using a first rate convolutional encoder while the signal transmitted from BTS_B is encoded using a second rate convolutional encoder. The signal is received at RF front end 201 and is down converted via down converter 202. The down converted signal is passed through analog to digital (A/D) circuitry 203 where it is converted into a digital format. The resulting digital signal is split into two signal paths (first and second) where despreading operations take place. In particular a first and a second Pseudo-Noise (PN) code is applied to each of the signal paths via mixers (despreaders) 204-205. The despread signal is further despread and de-modulated via despreaders 206-207. More particularly, cell and channel-specific spreading codes are utilized to despread the signal to recover the transmitted information. The first despreader 204 despreads data transmitted from the first base station (BTS_A) while the second despreader 205 despreads data transmitted from the second base station (BTS_B).

The transmitted information is de-interleaved by de-interleavers 208-209 resulting in demodulated symbols for the different links. More particularly, for each bit that was transmitted by BTS_A using a rate $^1/_n$ encoder, n symbols ($r_1^A, r_2^A, \ldots, r_n^A$) are eventually output by the de-interleaver. For example, if BTS_A is utilizing a rate $^1/_3$ convolutional encoder, then the de-interleaver receiving the signal for BTS_A would output three symbols (r_1^A, r_2^A, r_3^A). As discussed above, since the multiple base station links may result in a different number of symbols being received for each bit transmitted, the symbols received for each link cannot be simply combined. Therefore, in the preferred embodiment of the present invention, the resulting symbols are passed to multiple branch metric determiners (circuits 210-211), where branch metrics (μ_i) for the symbols are obtained.

The generation of branch metrics is well known in the art, and are generally calculated as

$$\mu_i = \sum_{j=1}^{n} s_{ij} r_{ij}, \quad n=1,2,3,\ldots$$

where

n=1, 2, 3, . . . is the number of the encoded symbols at the output of the encoder corresponding to one input bit;
s_{ij} =+ /- 1, is the jth symbol of the output of the convolutional encoder for the ith state (or branch)
r_{ij} = is the jth symbol of the received sequence for the ith branch (or state) of the convolutional decoder and
i represents the ith state (or branch) of the decoder.

For example, for three-way intersystem soft handoff where base stations A, B, and C are using ½, ¹/₃, and ¼ rate convolutional encoding, respectively, the branch metrics for the ith branch for base stations A, B, and C would be:

$$\mu_i{}^A = s_{i1}^A * r_{i1}^A + s_{i2}^A * r_{i2}^A,$$
$$\mu_i{}^B = s_{i1}^B * r_{i1}^B + s_{i2}^B * r_{i2}^B + s_{i3}^B * r_{i3}^B,$$
$$\mu_1{}^C = s_{i1}^C * r_{i1}^C + s_{i2}^C * r_{i2}^C + s_{i3}^C * r_{i3}^C + s_{i4}^C * r_{i4}^C,$$

Thus, in accordance with the preferred embodiment of the present invention first branch metric determiner 210 generates branch metrics for symbols generated utilizing a first encoding scheme, while second branch metric determiner 211 generates branch metrics for symbols generated utilizing a second encoding scheme.

After the ith branch metrics for the base stations are computed, the branch metrics for each base station are passed to combiner 212 where they are combined and output. More particularly the final branch metric for the ith branch would be output as

$$\mu_i = m_i^A + m_i^B + m_i^C .$$

Because the branch metrics from each of the base stations are added together to form a combined branch metric, the diversity combining gains of soft handoff can be achieved for inter-system (generation) soft handoff.

After summing, the summed metrics are passed on for further decoding. The decoding process is well known in the art and utilizes a Viterbi Algorithm as

described in Digital Communications Fundamentals and Applications, N.J., Prentice Hall, 1988.

It should be noted that in the preceding discussion reception of two and three signals transmitted from two and three base stations was described. One of ordinary skill in the art will recognize that the present invention can be applied to reception of more than three signals from multiple sources (i.e., base stations or mobile units). In the situation where more than three signals are being received, the receiver will require an additional signal branch for each signal received. In particular, if three signals are being received from three differing base stations, the receiver of FIG. 2 will require the addition of another signal branch to produce branch metrics for the third base station. The branch metrics from the third base station will be combined with the branch metrics from the other base stations via combiner 212. This is illustrated in FIG. 3 where a block diagram of the decoder of FIG. 2 is shown. As shown in FIG. 3, three branch metric generators 301-303 are receiving symbols from three base stations (A, B, and C). As is evident, base station A utilizes a rate ½ convolutional encoder while base stations B and C utilize rate $^1/_3$ and ¼ encoders, respectively. As shown, branch metric generators 301-303 generate branch metrics for the input symbols and outputs the branch metrics to combiner 304. Combiner 304 combines branch metrics from each of the receiver's receive paths. This allows for the diversity combining gains of soft handoff for inter-system (generation) soft handoff. More particularly, because branch metrics are determined prior to combining the receive paths, the receiver is capable of combining signals that are encoded with varying convolutional encoding rates.

FIG. 4 is a flow chart showing operation of the decoder of FIG. 3 in accordance with the preferred embodiment of the present invention. The logic flow begins at step 401 where a plurality of symbols is received from a plurality of base stations. In the preferred embodiment of the present invention the symbols from each base station are transmitted utilizing a differing convolutional encoding scheme for the same information sequence. In particular, each encoder from the plurality of base stations utilizes a differing encoding rate. At step 403 branch metrics are determined for each of the plurality of base stations based on the received symbols from each base station. In particular, the symbols received from a first base station are utilized to determine branch metrics for the first base station, while the symbols received from a second base station are utilized to

determine branch metrics for the second base station. After the branch metrics of the plurality of base stations are determined, the branch metrics are combined to produce a combined branch metric (step 405). Finally, at step 407 the combined branch metric is utilized for decoding the received transmission.

In certain situations the frame structure will differ based on what convolutional encoding rate is being utilized. For example, the ¼ and $^1/_8$ frame of IS-95A/B do not have cyclic redundancy check bits (CRC bits), while the IS-2000 standard requires a 6 bit CRC for both ¼ and $^1/_8$ frames. Because of this, the simple combining of the frames by combiner 304 cannot be accomplished. In order to solve this problem, logic circuitry is provided in an alternate embodiment.

In the alternate embodiment the logic circuitry expands frames with no CRC bits by inserting zeroes where the CRC bits for the next-generation protocol should exist. FIG. 5 is a block diagram of decoder 500 in accordance with an alternate embodiment of the present invention. As shown, logic circuitry 501 has been inserted prior to branch metric generators 301-303. Logic circuitry 501serves to insert zeros into the received frames at various time periods. Operation of decoder 500 in accordance with the alternate embodiment of the present invention occurs as shown in FIG. 6.

The logic flow begins at step 601 where logic circuitry 501 determines the encoder rates for the plurality of received signals. At step 603 it is determined where CRC bits exist within the various frame formats. The logic flow continues to step 605 where it is determined if all frame formats are similar, and if so the logic flow continues to step 607 where the received symbols are passed to branch metric generators 301-303. If, however, it is determined that the frame formats for the received frames are different, then the logic flow continues the step 609 where logic unit 501 inserts zeros in frames having no CRC bits. The logic flow continues to step 607.

In the alternate embodiment of the present invention the number of CRC bits inserted into the frame is determined by the frame formats for those frames having CRC bits. For example, if a frame comprises 6 CRC bits, then logic unit 501 will insert 6 zeros into the appropriate spot in those frames with no CRC bits so that the frames may be properly combined. Such insertion is illustrated in FIG. 7. As shown, a frame received from BTS_A has 6 CRC bits entering logic unit 501, and the frame received from BTS_B has no CRC bits. In the alternate embodiment

of the present invention, logic unit 501 will insert 6 zeros into the appropriate spot in the frame received from BTS_B.

While the invention has been particularly shown and described with reference to a particular embodiment, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention. It is intended that such changes come within the scope of the following claims.